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An experimental investigation of the performance of a new wideband, directional receiver/transmitter sonar system

John Fawcett
Richard Fleming

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2009-174
August 2009

Canada

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Abstract

In this report, we describe a wideband projector/4-element receiver sonar system that we constructed. The wideband projector was a medium frequency multi-mode pipe projector and four wideband; rectangular 1-3 piezocomposite hydrophones were used as receive elements. The combined projector/receiver system has a combined beamwidth of about 2 degrees at a frequency of 45 kHz. The directional characteristics depend significantly upon the frequency. Measurements of the projector's transmit voltage response (TVR) curves and the projector's and receive elements' beampatterns were carried out at the DRDC Atlantic barge facility and are described. This wideband system was tested in the DRDC Atlantic acoustic calibration tank and at the barge in a series of target-scattering detection/classification experiments that are described. In particular, one of the targets was a small aluminum-shelled float. A hole was drilled into the float that allowed different materials to be placed within and it was found that these resulting objects could be discriminated based on their echo. Finally, we conclude with a discussion of some of the problems that were encountered and future work.

Résumé

Dans le présent rapport, nous décrivons un projecteur à large bande/système sonar à récepteur à quatre éléments que nous avons construit. Le projecteur à large bande est un projecteur à tube multimodes à moyenne fréquence et quatre largeurs de bande, qui utilise des hydrophones piézocomposites à connectivité 1-3 rectangulaires comme éléments récepteurs. Le système projecteur/récepteur combiné possède une largeur de bande totale d'environ 2 degrés à la fréquence de 45 kHz. De plus, les caractéristiques directionnelles dépendent beaucoup de la fréquence. Les mesures des courbes de réponse en tension d'émission du projecteur et des diagrammes du projecteur et des éléments de réception ont été réalisées à l'installation de la barge de RDDC Atlantique et sont décrites dans le présent rapport. La mise à l'essai de ce système à large bande a été faite dans le bassin d'étalonnage acoustique de RDDC Atlantique et dans la barge, au moyen d'un ensemble d'essais de détection/classification de diffusion de la cible, également décrit dans le présent rapport. En particulier, une des cibles était un petit flotteur à revêtement en aluminium. Un trou a été percé dans ce flotteur pour y insérer les diverses matières, et on a découvert que l'on pouvait distinguer les objets ainsi obtenus en fonction de leur écho. Finalement, nous examinons certains problèmes rencontrés ainsi que les recherches futures.

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Executive summary

An experimental investigation of the performance of a new wideband, directional receiver/transmitter sonar system

R. Fleming; J. Fawcett; DRDC Atlantic TM 2009-174; Defence R&D Canada – Atlantic; August 2009.

Introduction: There are many sonar applications where it is desirable to be able to classify a detected echo. For example, one may wish to determine an echo corresponding to a fish or a scuba tank, a mine or a rock, a ship hull or a limpet mine, etc. The ability to discriminate the echoes of objects of interest from those that can be ignored can significantly reduce the amount of time required for further investigation. In previous reports, we described the multi-mode pipe projector that allowed us to utilize very wideband pulses. The scattering experiments in these cases were done with a projector and a single omni-directional hydrophone at very short ranges. In this report, we consider a planar array of directional receivers and for some of the measurements consider ranges as large as 12.75m.

Results: It was found that the combined projector/receiver system has narrow beamwidth characteristics, particularly at higher frequencies. The system showed good potential for the classification of targets, even when the targets only differed in terms of the interior fills. It was shown, that the system could be used at significant ranges. With the configuration used there was significant non-linearity in the response of the receive elements, particularly for frequencies less than 10 kHz.

Significance: A wideband system with directional receive elements is able to detect and discriminate small targets at significant ranges. The experiments also indicate the potential of using wideband scattering information to classify targets of similar geometrical shape but with different internal material compositions.

Future plans: The system investigated in this report is promising. We would like to improve the low frequency response of the system. For the experiments of this report, the four receive elements were simply wired in parallel, producing a single timeseries. In the future, we would like to record these separately in order to allow improved beamforming. Also, different geometric configurations of the receive elements could be investigated. In addition, the optimal incident pulse from the projector in terms of detection/classification capability and limiting the interfering signal at the receivers should be further investigated.

Sommaire

An experimental investigation of the performance of a new wideband, directional receiver/transmitter sonar system

R. Fleming; J. Fawcett; DRDC Atlantic TM 2009-174; R & D pour la défense Canada – Atlantique; Août 2009.

Introduction : Dans de nombreuses applications sonar, on doit pouvoir classifier un écho détecté. Par exemple, on peut décider de déterminer si l'écho correspond entre autres à un poisson ou à une bouteille d'air comprimé, à une mine ou à une roche, à la coque d'un navire ou à une mine limpet. La capacité de discriminer les échos d'objets qui présentent un intérêt et ceux qui n'en ont pas peut réduire considérablement le temps nécessaire pour d'autres expériences. Dans les rapports précédents, nous avons décrit le projecteur à tube multimodes qui nous a permis d'utiliser des impulsions à très large bande. Les essais de dispersion dans ce cas ont été réalisés avec un projecteur et un hydrophone omnidirectionnel simple à très courtes portées. Dans le présent rapport, nous examinons un réseau planaire de récepteurs directionnels, et pour certaines des mesures, il faut examiner des portées aussi grandes que 12,75 m.

Résultats : On a découvert que le système projecteur/récepteur combiné possède des caractéristiques de largeur de faisceau étroit, notamment aux fréquences élevées. Le système est potentiellement intéressant pour la classification des cibles, et ce, même si la seule différence entre ces cibles est le type de remplissage. On a en outre montré que le système peut être utilisé pour des distances importantes. Pour la configuration utilisée, la réponse des éléments de réception comportait une non linéarité importante, notamment aux fréquences inférieures à 10 kHz.

Portée : Un système à large bande doté d'éléments de réception directionnelle peut détecter et discriminer des petites cibles sur de grandes distances. Les expériences ont aussi permis de montrer la possibilité d'utiliser les informations de diffusion à large bande pour classifier les cibles de forme géométrique similaire, mais dont la composition interne est différente.

Recherches futures : Le système étudié dans le présent rapport est prometteur. Nous aimerions améliorer la réponse en fréquence faible du système. Pour les expériences présentées dans le présent rapport, les quatre éléments de réception ont simplement été raccordés en parallèle, ce qui a produit une seule série chronologique. Plus tard, nous aimerions enregistrer ces informations séparément afin d'améliorer la formation du faisceau. Les diverses configurations géométriques d'éléments de réception pourraient en outre être étudiées. Il faudrait aussi étudier l'impulsion incidente optimale produite par le projecteur sur le plan de la capacité de détection ou de classification et de réduction du signal brouilleur aux récepteurs.

Table of contents

List of figures

Acknowledgements

We acknowledge the assistance of Rich Johnson and David Doucette of DRDC Atlantic's calibration barge for their assistance in calibrations and measurements taken at the ACB.

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1 Introduction

There are many active (and passive) sonar examples where it is very desirable to be able to classify an echo as corresponding to an object of interest or an echo that, although detectable, can be safely ignored. In the case of imaging sonar's, the differences between significantly different-sized objects are readily apparent. A more challenging classification problem is when various objects are outwardly geometrically similar but are structurally different. Some examples of this situation are a rock versus a mine, a crab-pot versus a mine, a compact school of fish versus a diver, etc. This concept is not new and there have been several other publications regarding the automated classification of objects from their frequency and/or frequency/aspect response [1-4].

In previous reports [5-6], we experimentally investigated the use of the Multi-Mode Pipe Projector (MMPP) to provide wideband pulses in transmission and scattering experiments. In [7-8] a set of dummy limpet mines and other objects were affixed to either an aluminum or a fibreglass disc and rotated below the fixed MMPP and a single omni-directional hydrophone at close range. It was demonstrated in these experiments that with the MMPP system one could successfully discriminate the various target echoes from the plate echo and from each other.

Although these previous experiments were conceptually successful, the projector/single omni-directional measurement system was not one that could be practically deployed at sea. In this report, we discuss the implementation of a MMPP projector (30X40) and an attached 4-element planar receive array. The receive elements are rectangular 1-3 piezocomposite hydrophones and are significantly directional over a wide band of frequencies [9]. For simplicity, in this report, these four elements were wired in parallel producing in hardware a broadside beam. In the future, we would like to adapt our present software to record the four elements separately to allow for improved beamforming.

In this report, we describe two sets of experiments that we carried out. The first set of measurements was carried out in the DRDC Atlantic acoustic calibration tank. Here, the projector/targets distances involved were small and were within nearfield distances of the projector. The second set of measurements was carried out at the DRDC Atlantic barge where much larger distances were considered. Here, the beam patterns and the transmit voltage response (TVR) of the projectors and the receive elements were also measured.

The TVR and beampattern measurements at the DRDC barge are first presented. We then describe the scattering/classification experiments carried out at the DRDC Atlantic acoustic calibration tank. Then, the longer distance scattering experiments at the DRDC barge are described.

2 Experimental set-up and results

In this section, we first describe the projector/receiver measurements (TVR, beampatterns) made at the DRDC Atlantic barge. We then describe the experiments carried out with the Wideband Interrogator (WBINT) system at the DRDC Acoustic Calibration tank and at the barge. Pictures of the WBINT system are shown below in Fig.1. Two versions of the system were constructed. The first prototype used a plywood mounting plate (1.9 cm thick) whereas the second prototype used a polyvinylidene chloride (PVC) mounting plate (1.25 cm thick). As seen in the pictures the hydrophones were arrayed such that the slot-fire acoustic energy from the MMPP would impinge on the edges of the hydrophones. The hydrophones were arrayed with 21.5 cm center-to-center spacing. It was thought that in this planar arrangement, the hydrophone recovery time from direct path acoustic energy would be reduced due to the null in the response of the hydrophones at this angle.

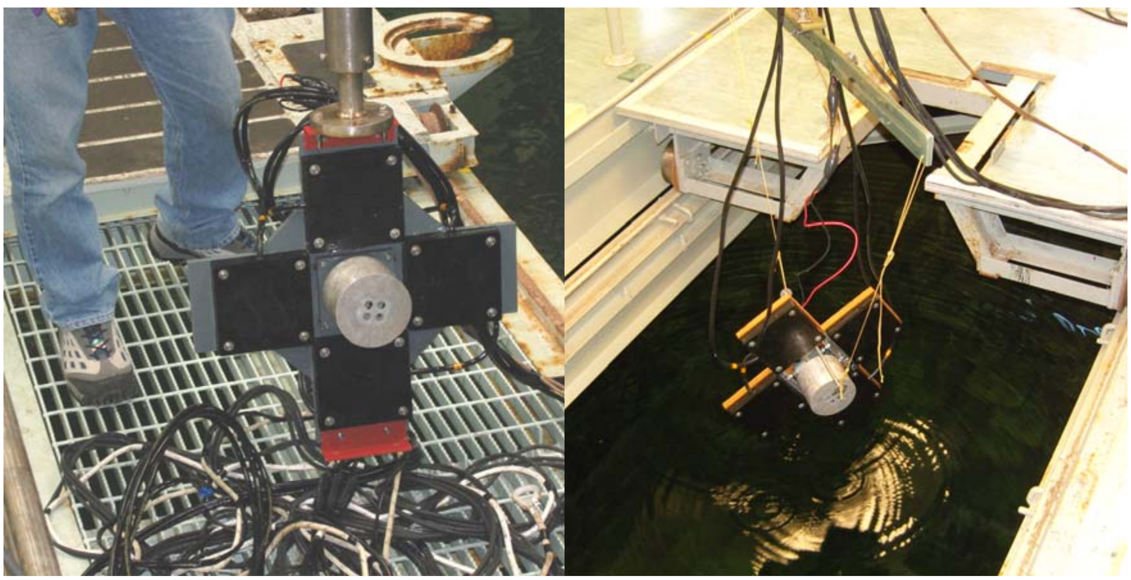

Figure 1. Wideband interrogator PVC version (L) and plywood version (R).

2.1 Transmit Voltage Response and beampattern measurements

The WBINT measurements are now described somewhat out of chronological sequence as we, in fact, performed the acoustic tank measurements before the barge measurements. We first describe the Transmitting Voltage Response (TVR) measurements made for the MMPP used with WBINT and for the rectangular receive elements. These receive elements were originally purchased as

wideband directional hydrophones that would be useful in investigating Canadian Patrol Frigate AN/SQS-510 sonar dome properties [9]. Selected TVR, receive sensitivities and beampattern measurements are shown in Figs. 2 - 4. These measurements were carried out using ACB-supplied reference hydrophones and projectors. The MMPP TVR measurements were made with respect to the endfire of the projector as that is the orientation used in the experiments. The endfire TVR of the MMPP when installed in the WBINT is seen in Fig. 2. The PVC-backing plate version of the WBINT was used in all of these measurements.

The MMPP TVR curves show a wideband response with reduced transmission in some frequency intervals (for example, 9 kHz, 41 kHz, etc).

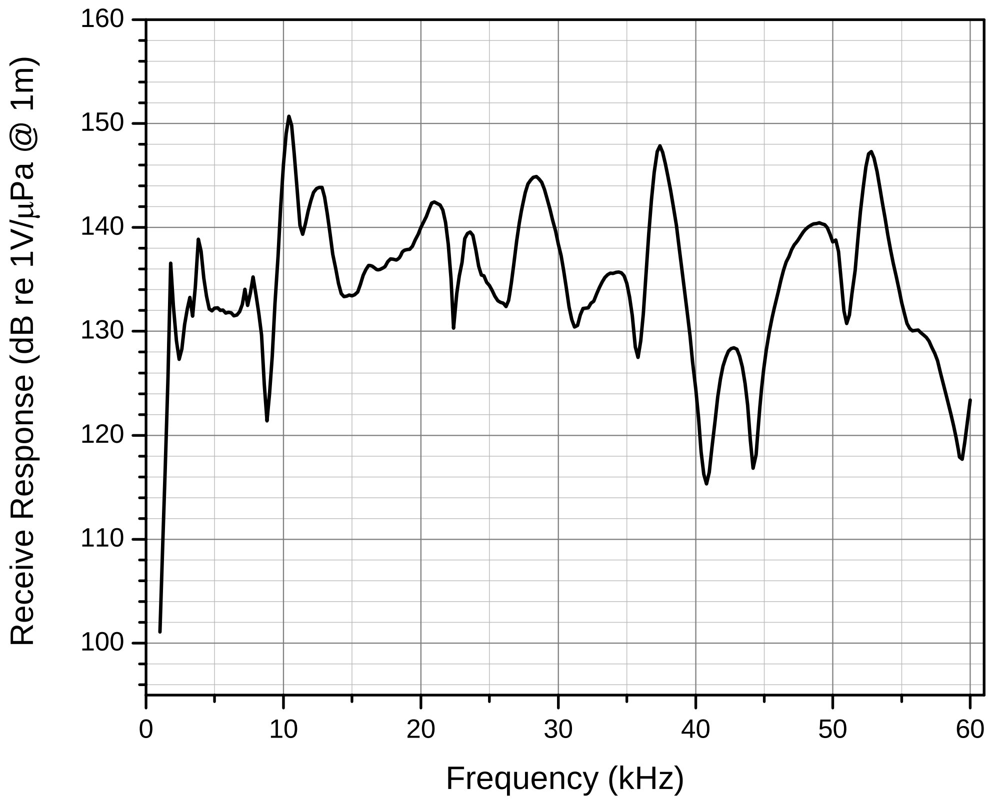

Figure 2. MMPP endfire transmitting voltage response.

A receive response measurement of an unmounted (freely suspended) versus WBINT-mounted 1-3 piezocomposite hydrophone (secured to PVC mounting plate with epoxy and bolts) can be seen in Fig. 3. The shape of the unmounted and mounted hydrophones are generally similar with some overall reduction in sensitivity. Of note is the erratic response below 8 kHz. This frequency band was investigated in subsequent WBINT tests and found to be of negligible utility.

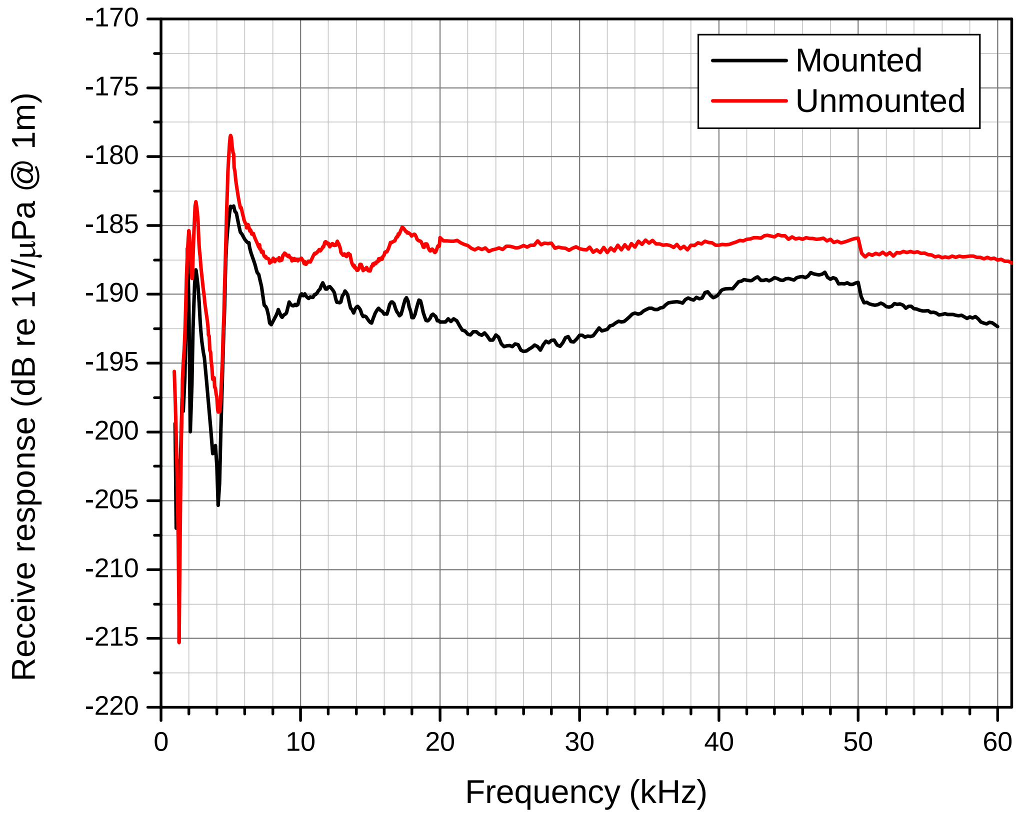

Figure 3. 1-3 piezocomposite hydrophone receive sensitivities both mounted and unmounted.

The beampatterns for both the projector and the receivers are significantly frequency-dependant with significant sidelobes at certain frequencies. Beampatterns of both the MMPP's transmissions and 1-3 piezocomposite hydrophone array receptions (all four electrically connected in parallel and mounted on the PVC backing plate) were taken. Given that the MMPP's beamwidth along its endfire direction is always larger than the beamwidth of the receive array, the hydrophones' beampattern is the predominant system beampattern. The receiver's main lobe becomes increasingly narrow as frequencies increase to the point where at 45 kHz, the effective mainlobe beamwidth (3dB down points) is about 2 degrees (see Fig. 4). Note the front/back asymmetry that comes about from the PVC mounting plate's insertion loss in the case of the hydrophones. In future work, this front/back ratio could be improved by installing appropriate damping layers on the rear surface of the WBINT hydrophone mounting plate. There is also some front/back asymmetry in the MMPP's beampattern because of the electrical connections on the MMPP's rear endcap.

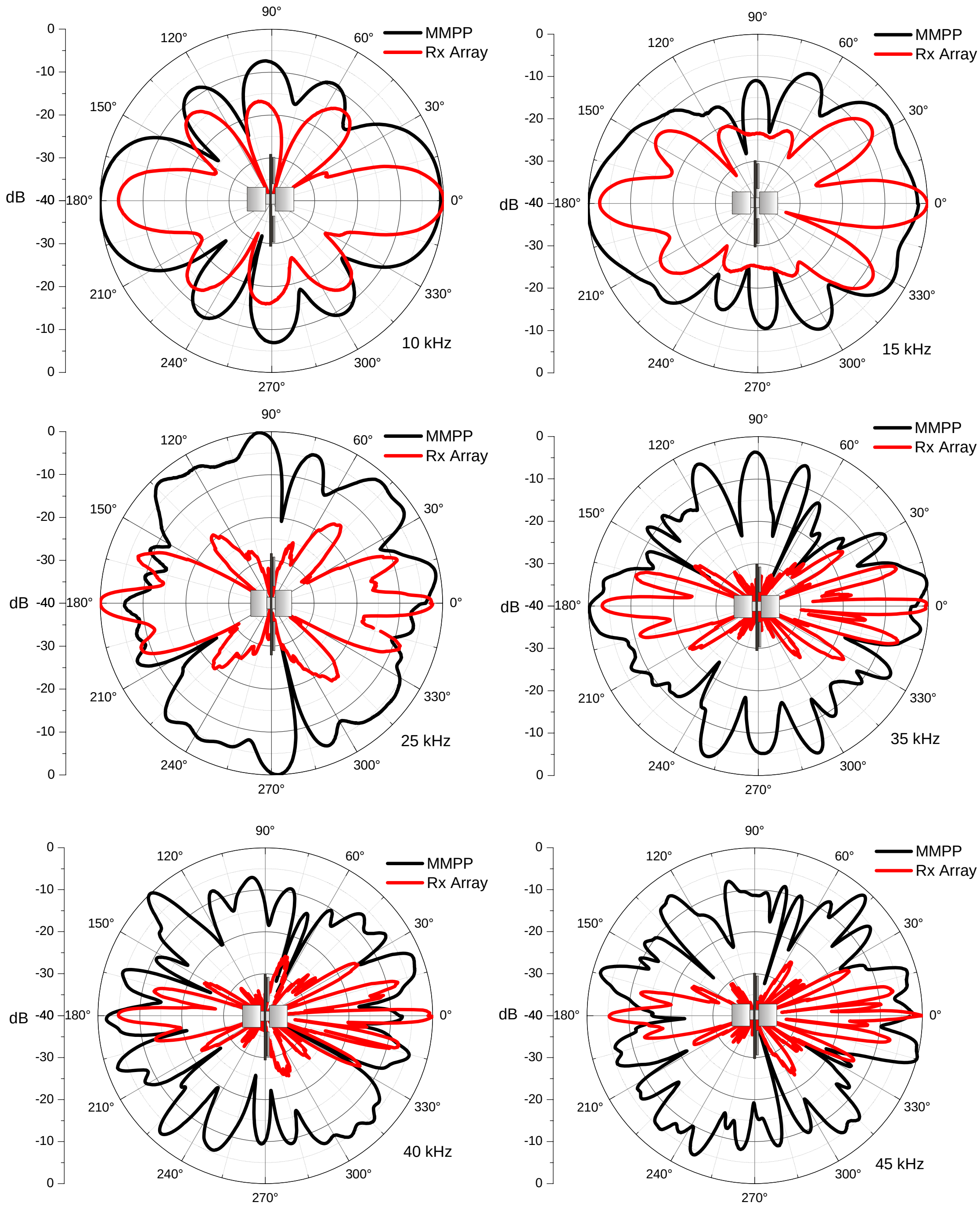

Figure 4. Selected MMPP/hydrophone array beampatterns.

2.2 DRDC Atlantic Acoustic Calibration Tank measurements

In the set of experiments at the DRDC Atlantic acoustic calibration tank, we considered a small spherical-like object (Grimsby float). This object has an aluminum shell of approximately 4mm

thickness with a small protuberance for tying off with rope. A hole was drilled in it allowing us to fill the sphere with different materials: (1) air (no fill) (2) water (3) half water (4) half water/half-steel ball bearings (5) small fraction of ball bearings. The hole was then plugged after the filling was changed. The sphere was attached to a wooden arm which was, in turn, attached to a rotation station pole and this system was rotated bringing the sphere into and out of the main beampattern of the projector/receive system. Photographs and a drawing of this setup are shown in Figs.5 and 6 respectively.

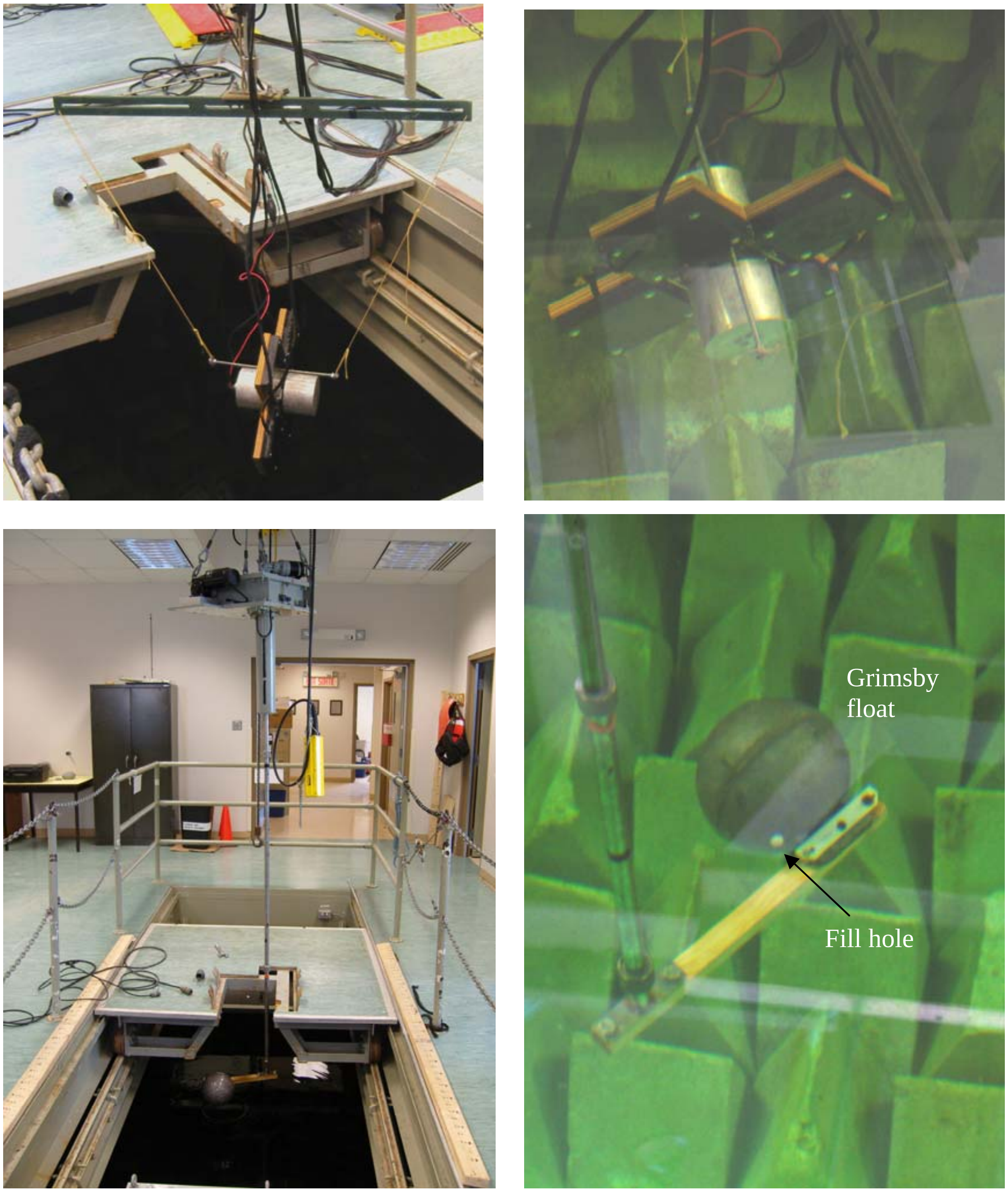

Figure 5. Calibration tank WBINT testing set-up images.

The distance from the projector to the rotator station pole was approximately 2m; the distance along the wooden arm to the front face of the sphere was approximately 43 cm. In the configuration used, the sphere was approximately in the main lobe of the projector for the distance of 2m. As the sphere approached its closest-point of approach at 1.57 m, the sphere is going out of the main beam of the projector. A set of ping/time series for each of these rotations were recorded. In addition, we repeated many of these measurements on different days. Although we tried to replicate the geometry of the setup exactly for each deployment, there were small variations each time. Thus, the data from the same target, but for different deployments is not identical. Because of the short ranges involved in these measurements and the narrow beam characteristics of the projector and receive elements at the higher frequencies, this resulted in observable differences in the data.

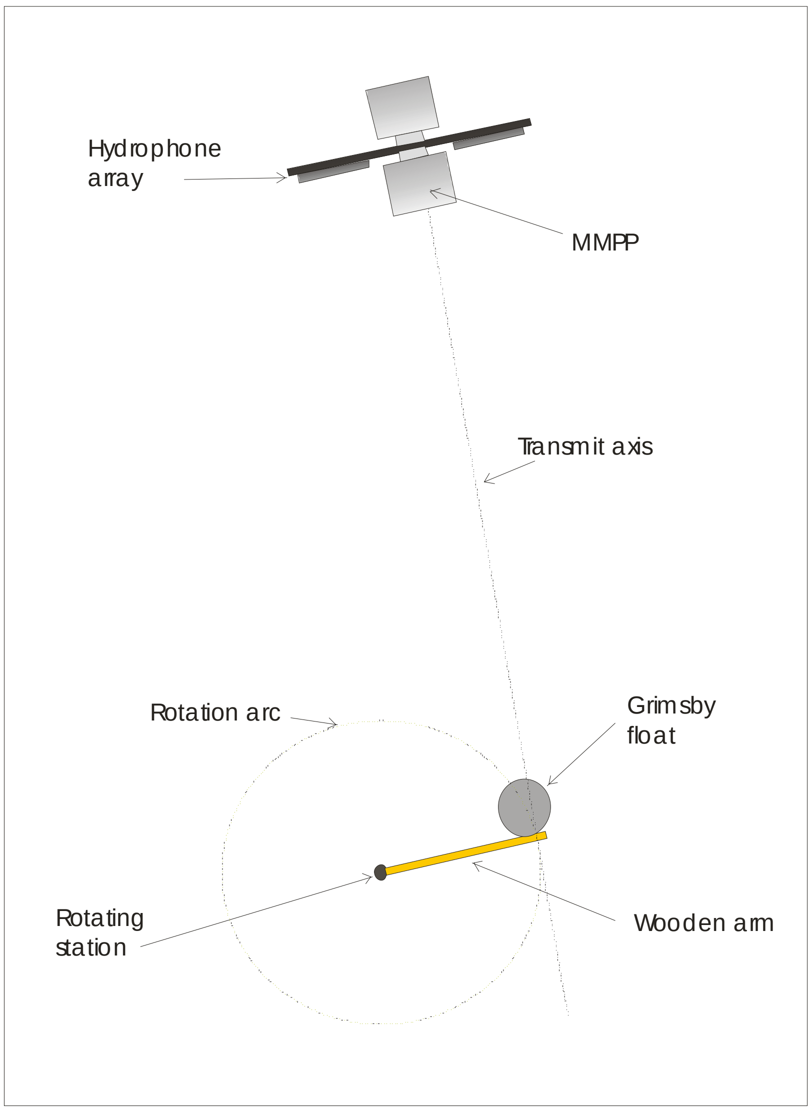

Figure 6. Sketch of calibration tank WBINT experiment.

One difficulty with echo measurements in the tank is the weakness of the echo relative to the incident pulse. Although we construct an incident pulse of very short duration at a suspended hydrophone, there is still a relatively large amount of incident energy for sufficiently long time that it can mask the echo. (One could move the target further away to improve this situation, but then various multipath arrivals from the various boundaries of the tank begin to arrive). The compensated, short pulse is constructed for the mainlobe energy from the endfire direction of the MMPP. However, this is not the incident pulse received by the four receive elements. These elements receive a combination of energy from the endfire and slot directions of the projector. In addition, we suspect that some energy propagates in the structure connecting the projector and the receive elements. Thus, the resulting incident energy received at these elements is complicated, in general, and relatively long in duration. In addition, it was found that the physical coupling of the projector caused low-frequency (maximum at approximately 5 kHz) vibrations of the element that further degrades the echo signal. As well, the hydrophones exhibit non-linear response below 8 kHz. This was mitigated by considering a [10 - 55] kHz pulse.

In Fig.7, we show the ping/time series history for the water-filled sphere. The echo is significantly weaker than direct pulse as seen at the receive elements and can be seen varying from about the 4 msec time to about 2.85 msec at the time of closest approach. Recall, that the sphere is at the end of a wooden arm. The arm is initially pointing away from WBINT, moves through the main beam of the projector and then, after passing through the main beam, continues to approach the projector. The main peak at the receive elements occurs at approximately the 1 msec time. This time is a little later than the actual pulse at the projector due to the travel time from the projector to the elements.

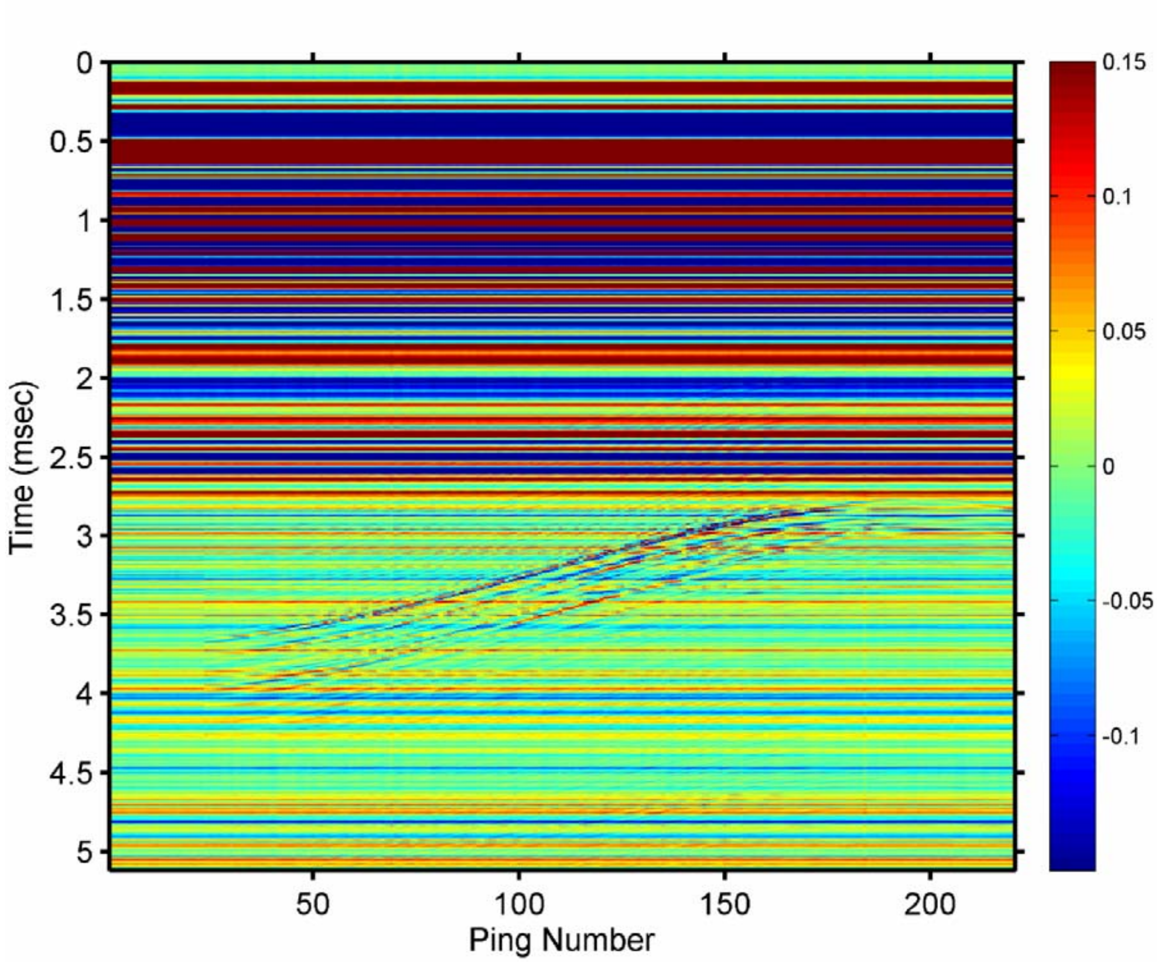

Figure 7. The ping/timeseries for the water-filled sphere. The echo from the sphere can be seen in approximately the 3 and 4 msec range. The image has been normalized by the maximum absolute value of the data.

From Fig.7, it can be seen that it is difficult to isolate the echo from the direct energy still evident at the receive elements. However, the direct energy is invariant with respect to the rotation of the sphere. In order to enhance the echo we will compute a mean background time series and compute the difference ping/time series. We also, initially filter the time series so that its frequency content lies within the interval [10 55] kHz. The resulting ping/time series are shown below in Fig.8 for the air-filled, water-filled, and water/ballbearing-filled spheres in a region near the echo. In some rotations, the first few pings seemed to contain poor data, through either recording “glitches” or non-rotation, so we actually deleted the first 25 pings for the mean computation and the output files. From Fig. 8, it can be seen that there are general observable differences between the echo time series, particularly, between the air- and water-filled cases. The water-filled case appears to have a generally longer duration echo.

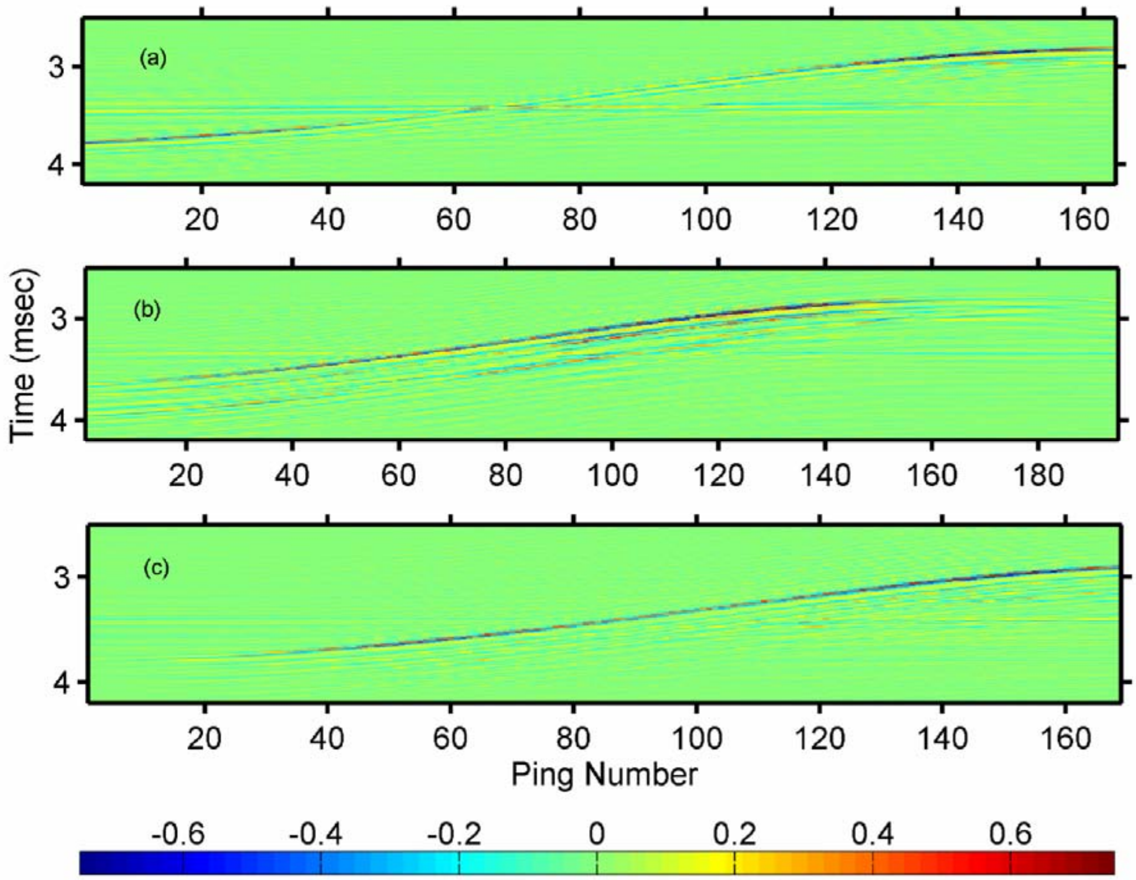

Figure 8. Ping/time series for rotating (a) air-filled sphere, (b) water-filled sphere, (c) water and ball bearing fill.

From each of the 11 sequences with the [10 55] kHz pulse, we find the echo with the maximum amplitude and then we take all the pings which have a maximum amplitude within 67% of this value. The maximum value of the ping is taken as the 21st point of the extracted echo and 80 points after the maximum value are included for a total length of 101 points. In Fig. 9, we show the composite of the extracted time series where the rotation sequences have been arranged so that all the rotation sequences from one sphere–type are shown together. In Figure 10, the corresponding Fourier spectra are shown. There are differences in the time series and the spectra between the various sphere-fills. However, there is also significant variation within each class type.

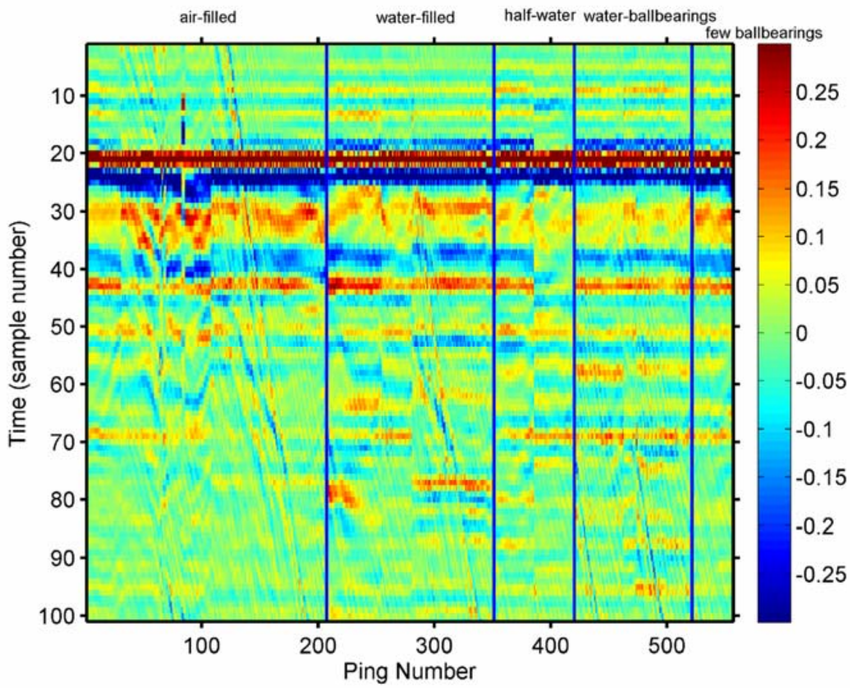

Figure 9. The extracted time series for the different sphere fillings.

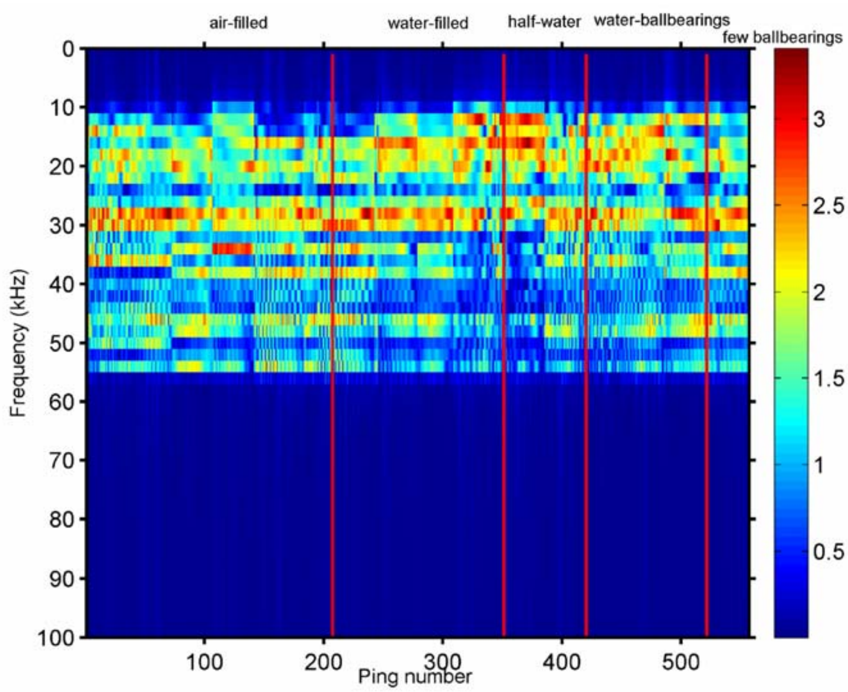

Figure 10. The Fourier spectra corresponding to the time series of Fig.9.

This is because the classes are combined from up to 3 rotation sequences for each fill type. It appears that due to the short distances and the beampatterns of the projector/receivers there was some variations between the different rotations, probably due to small changes in the geometry of the setup. Even within the same rotations, there are significant changes in the echoes due to the changing scattering geometry.

For each of the extracted ping/time series we compute 4 features for each of these time series. In particular, these features are: (1) the lacunarity of the amplitude of the time series (variance/mean squared-1), (2) the ratio of the mean amplitudes of the intervals of time series points [15 41] to [42 101], (3) the ratio of the mean spectral amplitudes in the frequency intervals [20 55] kHz to [10 20] kHz and (4) we compute a short-time, time-FFT spectrum and for the frequency interval [10 55] kHz we compute the lacunarity of the time/spectral amplitude values. With these features, we select a random set of 7 for each class to train a classifier, and use the remainder to test the classifier. We use a kernel-based linear regression classifier [2] and we perform a random partitioning of the data into training and testing 61 times to compute an average Confusion matrix. The (j, k) element of the Confusion matrix represents the fraction of times that the j*th*-class object is classed as a k*th*-class object. The sphere which was mostly air, but contained only a few ball bearings was not used in the training, so there are no column entries in the Confusion matrix for this object. However, this object is used in the testing set and it is interesting to see which classification this object is given. The elements of the resulting Confusion matrix are given in Table 1.

	Air-filled	*Water-filled*	*Half-water*	*Water-ballbearings*	*Almost air*
Air-filled	*0.87*	*0.07*	*0.07*	*0.03*	
Water-filled	*0.08*	*0.57*	*0.18*	*0.16*	
Half-water	*0.09*	*0.17*	*0.60*	*0.14*	
Water-ballbearings	*0.01*	*0.20*	*0.13*	*0.66*	
Almost air	*0.91*	*0.06*	*0.04*	*0.0*	

Table 1. Confusion matrix for classiifcation of sphere interior.

The results of the Confusion matrix are very reasonable. The air-filled sphere is classified correctly 87% of the time. The water-filled sphere is classified correctly 57% of the time but it is “confused” most frequently with the half-water/half-air sphere 18% and the half-water/half ball-bearings 16% of the time. The almost air-filled sphere is classified as the air-filled sphere 91% of the time.

2.3 Barge Trial Data

The experiments in the acoustic calibration tank were somewhat limited by the short projector/target distances which could be used. We now describe a set of target scattering experiments that were carried out at the DRDC Atlantic barge facility. Many of the problems described for the calibration tank also occurred at the barge. Pulses with lower frequency content seemed to excite the projector/receiver structure causing a significant interference with any echo return. In addition, our standard procedure of compensating the input waveform to produce an output pulse with a flat spectrum seemed to be counter-productive: (1) it significantly reduces the output level of the projector because it effectively reduces any peaks in the projector TVR to the lower levels of the TVR (2) the “incident” pulse received at the receive elements is not from the main endfire beam of the projector and thus this received pulse is not “short” in duration. For the results described here, we used a pulse in the range [15 45] kHz and the received signal was filtered before digitization to lie above 8 kHz, and we simply used an uncompensated waveform which is flat in the interval [15 45] kHz. The TVR curve has a null region near 40-45 kHz so effectively the waveform was [15 40] kHz. In future experiments, we would like to extend this frequency interval, particularly for lower frequencies, but this will involve some mechanical decoupling of the projector from the receive elements or by use of more conventional hydrophones that do not exhibit the sub-8 kHz variations as seen in the 1-3 piezocomposite units.

For the first run, the Grimsby sphere is air filled and is located approximately 3.15 m from the projector. The projector and the sphere are both at 10.5 m depth. The projector is initially pointed away from the sphere and, in fact, it first ensonifies a Fitzgerald projector which was deployed at about 4.5 m away. The ping/time history is shown in Fig. 11 as the WBINT is rotated thus pointing at various suspended objects and the barge. The return from the sphere is visually evident. The sphere was then removed, was filled with water and then redeployed. The resulting ping/time history is shown in Fig.12 and once again, the returns from the sphere and Fitzgerald are easily visible.

In Figs. 13 and 14, we show the resulting ping/time history for the water-filled sphere and for a small, thin, solid steel cylinder, whose length is 45 cm and diameter 7 cm (see Fig. 15). In these cases, the projector/target distance was 6.5 m. The sphere’s echo can be seen in Fig.13 but is weaker than in Fig.14 where the echo from the cylinder is stronger. The thin lines, which run throughout the figures, are due to electrical “spike-like” features, which were observed running through the acoustic time series. Finally, in Fig.16 the ping/time history for the cylinder at a range of 12.75m is shown. The cylinder echo is still evident. The top-surface reflected pulse from the projector is also evident. Some reflections from the sides of the barge can also be seen. We extracted 500 pings and a section of 1024 time points around each of the target echoes and then took the FFT of each of these arrays. The resulting spectra are shown in Fig.17. It can be seen that: (a) the spectra for the air-filled sphere, the water-filled sphere and the cylinder are visually different and (b) the spectra for the water-filled spheres at the 2 ranges are similar as are the 2 sets

of spectra for the cylinder. These results are very encouraging for the possibility of using the spectral characteristics to classify the object. In these cases, operationally realistic ranges are considered but are constrained by the dimensions of the barge's inner pool.

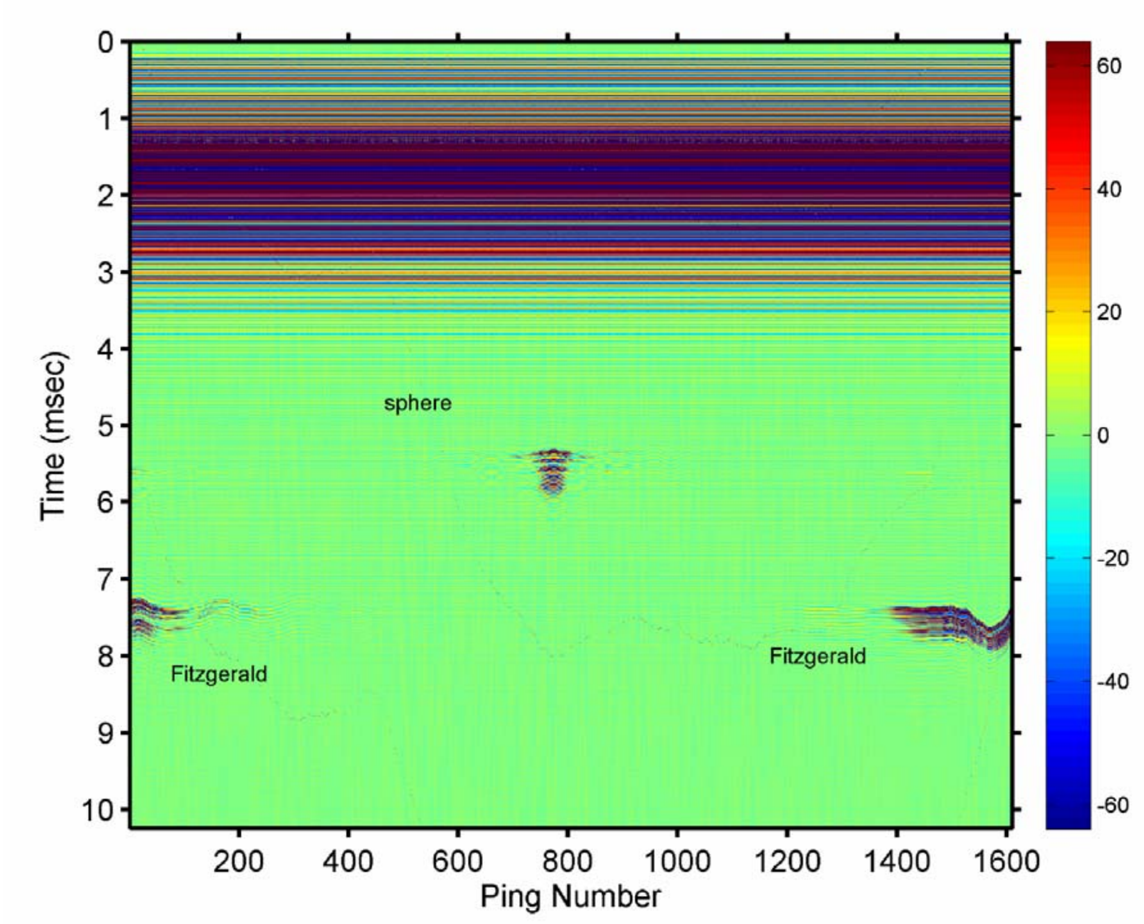

Figure 11. The ping/time series for the air-filled sphere at approx. 3.15 m range.

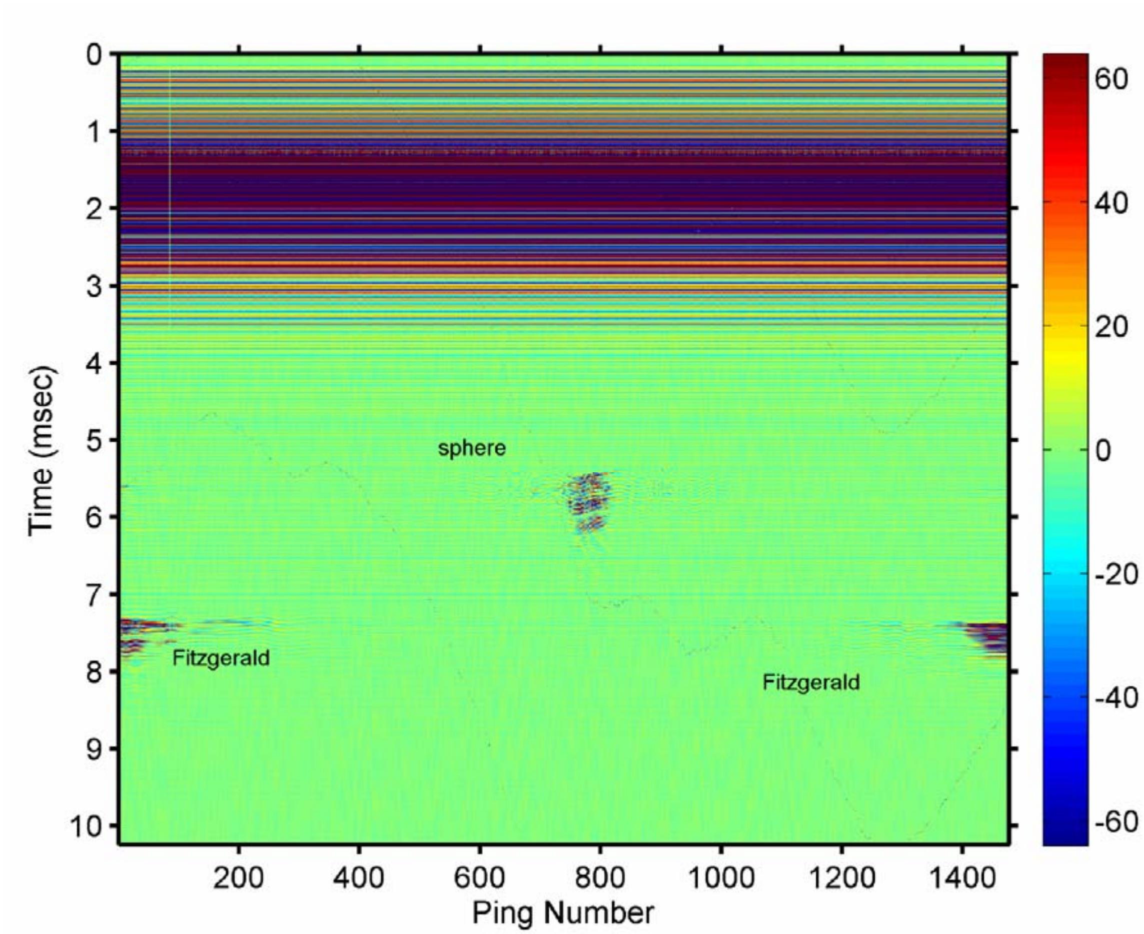

Figure 12. The ping/time series for water-filled sphere at approx. 3.15 m range.

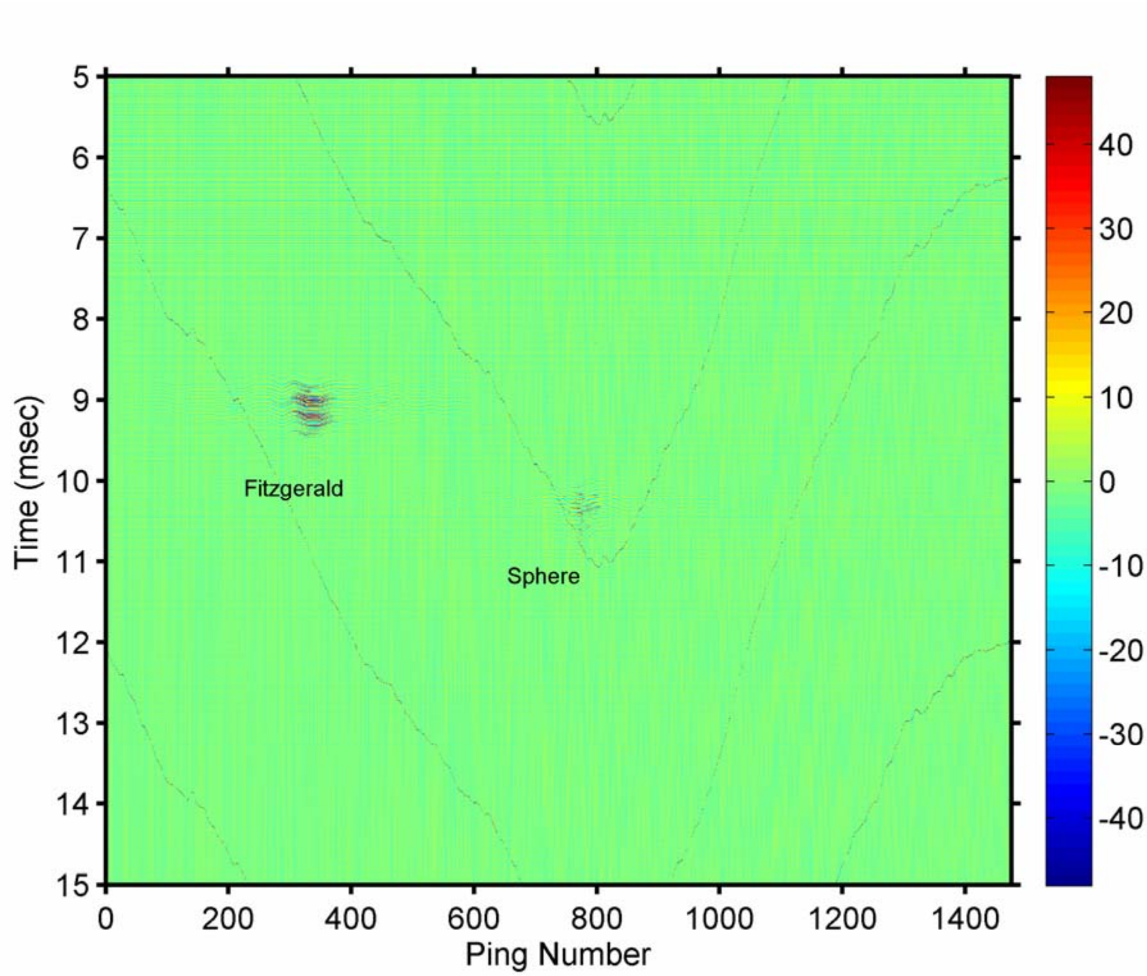

Figure 13. The ping/time history for water-filled sphere at 6.5m.

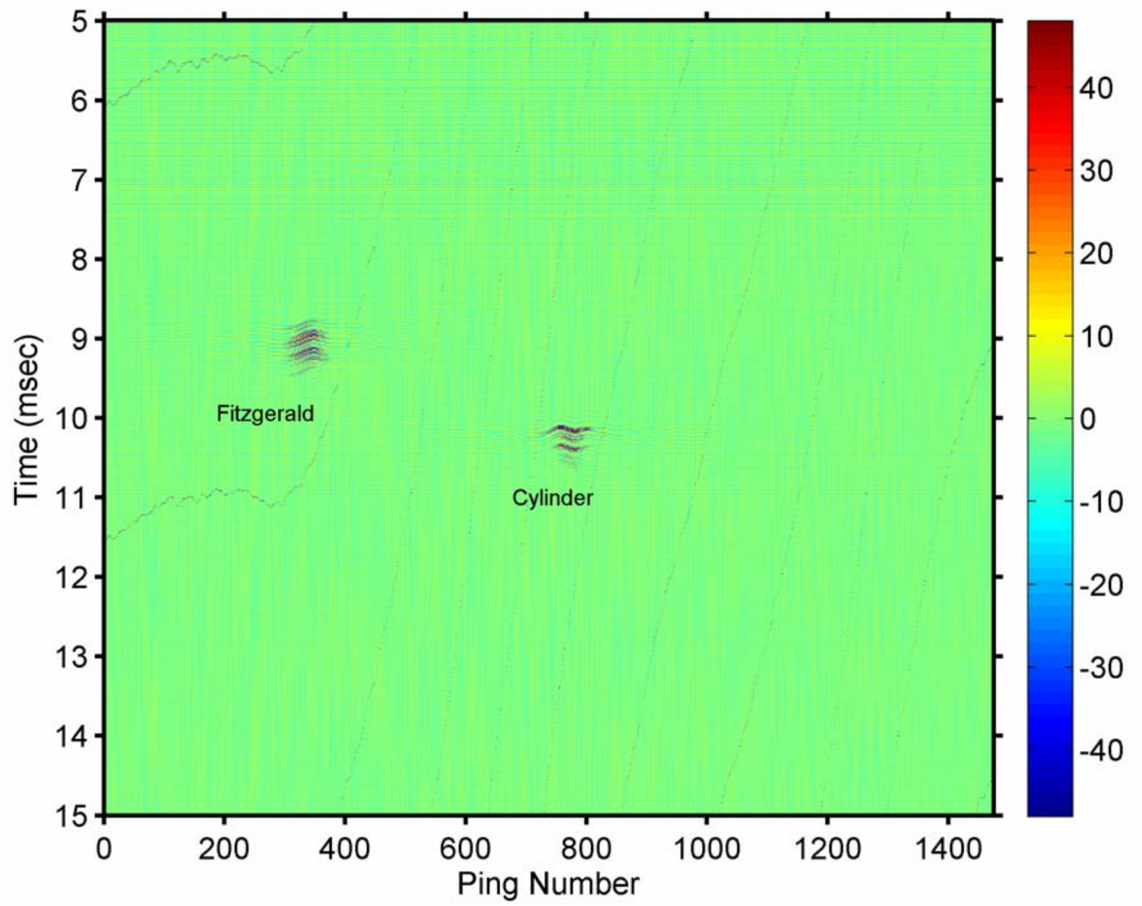

Figure 14. The ping/time history for cylinder at 6.5m.

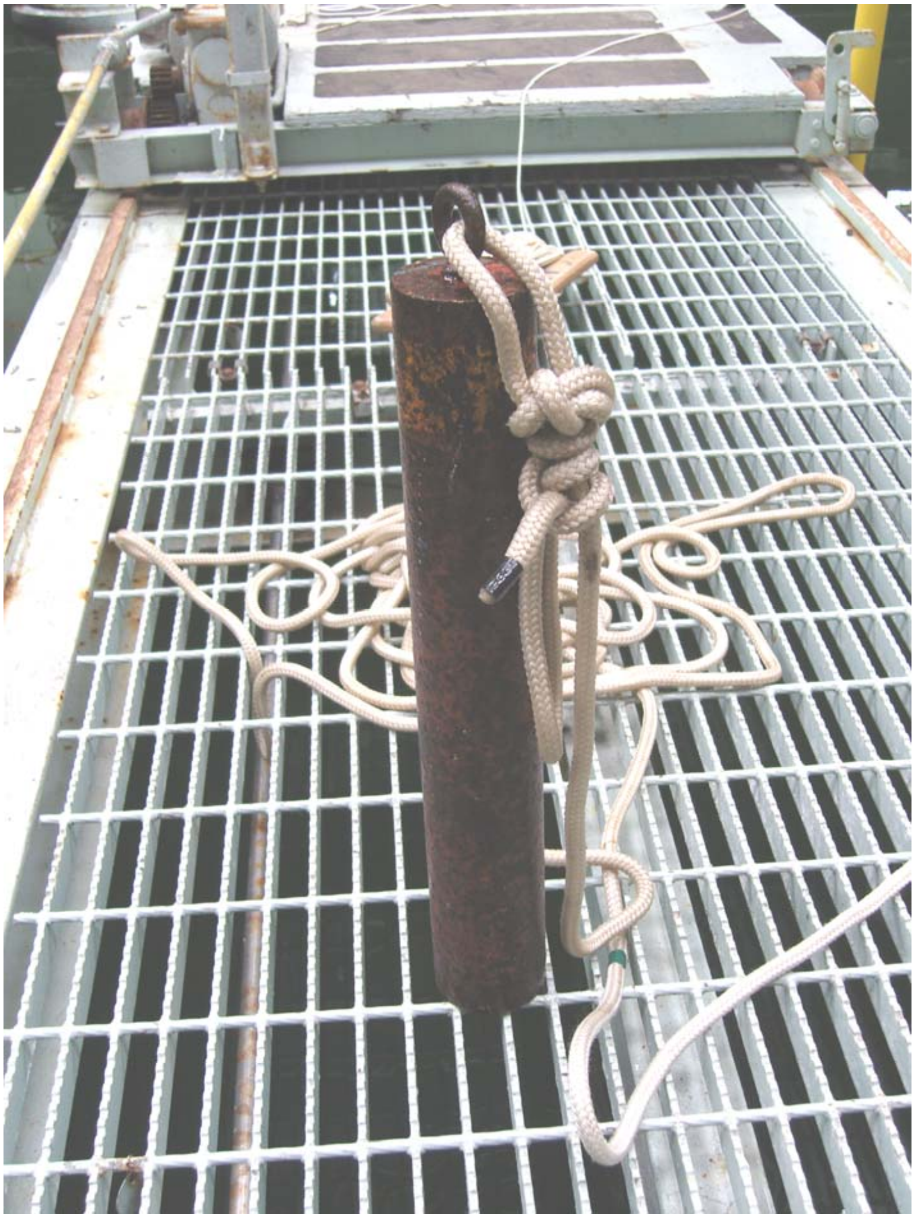

Figure 15. Solid steel cylinder.

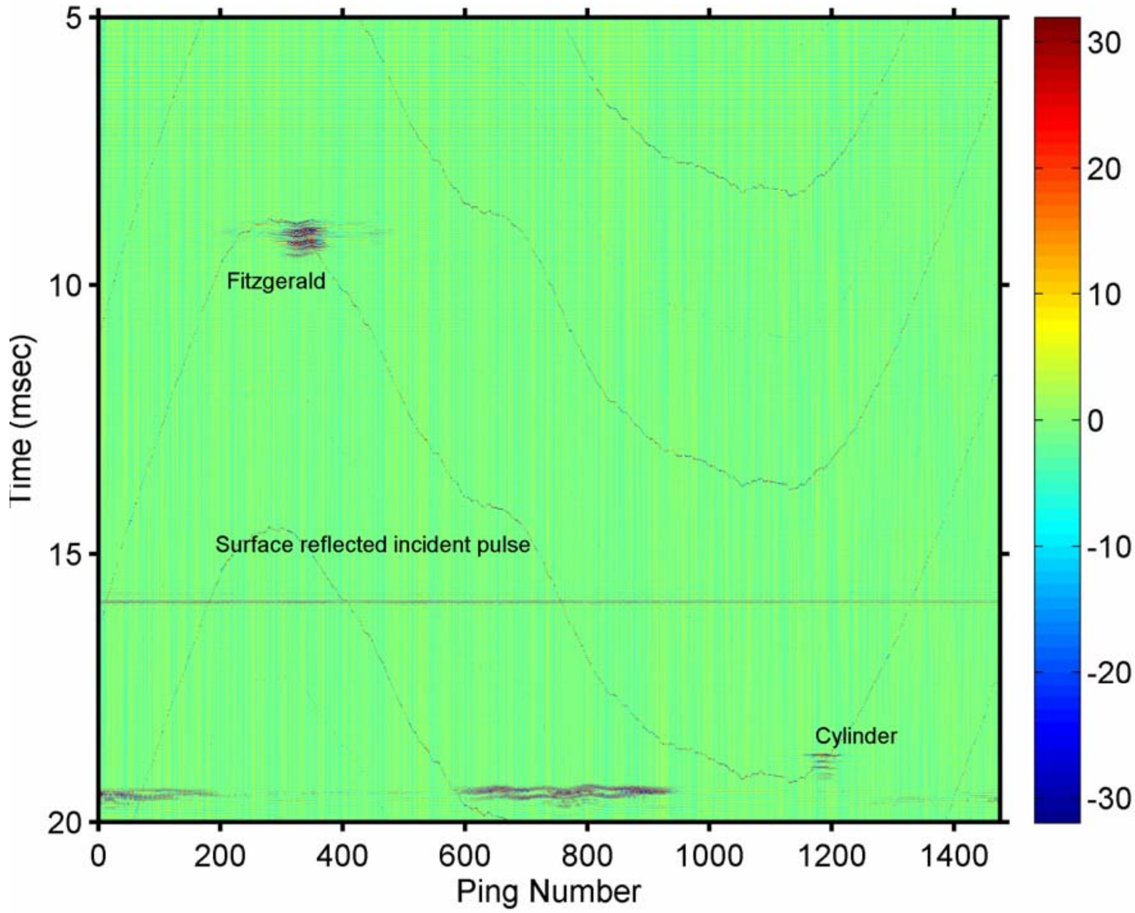

Figure 16. The ping/time history for the cylinder at 12.75m.

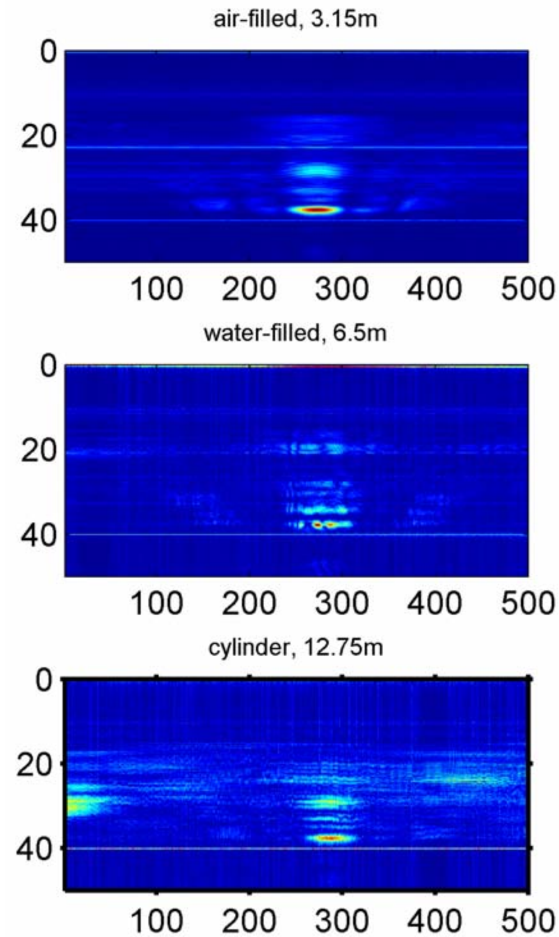

Figure 17. The Fourier spectra of the scattered echoes (amplitude). For each of the subplots, the values have been normalized so that the peak value (excluding the zero frequency) is unity.

3 Summary and Discussion of Results

We have described a simple wideband projector/4-element receiver sonar system. The combined directionalities of the receive elements results in system which effectively receives echoes over a narrow beamwidth. As would be expected, this beamwidth is quite wide (20°) at 10 kHz decreasing to 2° at 45 kHz. This directionality increases the signal-to-noise ratio of energy received from a target when the sonar is pointing at the target. The wide spectral bandwidth of the system yields sufficient “information” for the classification of targets.

From the tank experiment, we were able to classify different types of interior fill for a small roughly spherical target. At the DRDC Atlantic barge, we demonstrated obtaining useful echoes from a small cylinder at 12.75m range. Some issues with the system were identified. There was possible mechanical coupling between the projector and the receive elements at the lower frequencies. The hydrophones also exhibit non-linear response below approximately 8 kHz. We hope to able to improve this situation and extend the pulses down to lower frequencies by utilizing different hydrophone mounting conditions.

In past experiments with the MMPP, we have often frequency-compensated the input waveform in order to obtain a desired output waveform. In particular, we have often produced a very short incident pulse corresponding to a flat spectrum. It is not clear for the present system what the best incident pulse should be. The frequency compensation reduces overall the output levels of the projector. Also, the incident pulse as seen by the receive elements is, in general, not short and will interfere with target echoes (at least, for short ranges). In the present configuration, we simply recorded the four receive elements combined as a single timeseries.

In the future, one could consider recording the elements individually and one could consider using more elements or in different arrangements. Another interesting concept is that the receive elements used in these experiments can also be used as wideband projectors themselves. Thus, one could envision a multiple transmit/receive system.

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List of symbols/abbreviations/acronyms/initialisms

ACT	Acoustic calibration tank
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
FFT	Fast fourier transform
HF MMPP	High frequency multi-mode pipe projector
kHz	kilohertz
MMPP	Multi-mode pipe projector
PVC	Polyvinyl chloride
R&D	Research & Development
TVR	Transmitting voltage response
WBINT	Wideband interrogator

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In this report, we describe a wideband projector/4-element receiver sonar system that we constructed. The wideband projector was a medium frequency multi-mode pipe projector and 4 wideband; rectangular 1-3 piezocomposite hydrophones were used as receive elements. The combined projector/receiver system has a combined beamwidth of about xx degrees at a frequency of xx kHz. The directional characteristics depend significantly upon the frequency. Measurements of the projector's transmit voltage response (TVR) curves and the projector's and receive elements' beampatterns were carried out at the DRDC Atlantic barge facility and are described. This wideband system was tested in the DRDC Atlantic acoustic calibration tank and at the barge in a series of target-scattering detection/classification experiments that are described. In particular, one of the targets was a small aluminum-shelled float. A hole was drilled into the float that allowed different materials to be placed within and it was found that these resulting objects could be discriminated based on their echo. Finally, we conclude with a discussion of some of the problems that were encountered and future work.

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MMPP; mine; detection; broadband

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